Federal Guidelines for Landfarming Petroleum Hydrocarbon Contaminated Soils

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ABSTRACT

The guidelines presented in this report provide information for the siting, design, operation, and monitoring of a landfarm for remediation of petroleum hydrocarbon contaminated soil at federal contaminated sites. Landfarming is an *ex situ* contaminated soil bioremediation technique that involves excavating and spreading contaminated material either in beds consisting of a thin, uniformly thick layer or in windrows. Remediation occurs by manipulating various conditions that stimulate aerobic microbial activity. Recommended for remediating petroleum hydrocarbon contaminated soil, landfarming is well suited to remote regions of Canada due to its simplicity and land-intensive requirements.

As a first step in developing these guidelines, existing landfarming guidelines and information from Canadian, U.S., and other foreign jurisdictions; other applicable organisations; remediation contractors; and researchers were reviewed and compared in the companion document *Development of Federal Guidelines for Landfarming Contaminated Soil – Review of Existing Guidelines* (SAIC Canada (draft), 2005). Recommendations from this review, as well as consultation with Environment Canada's regional contaminated sites experts, aided the development of the guidelines presented herein.

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1 PREAMBLE

SAIC Canada has been contracted by the Contaminated Sites Division of Environment Canada to undertake a review of existing guidelines for landfarming and, based on this review, to recommend guidelines for the landfarming on federal land of soils from federal contaminated sites. This project produced the *Development of Federal Guidelines for Landfarming Contaminated Soils – a Review of Existing Guidelines* (SAIC Canada (draft), 2005) and this document: *Federal Guidelines for Landfarming Petroleum Hydrocarbon Contaminated Soils*. Although the Guideline is a stand alone document, for the rationalization of the criteria recommended, the Guideline Review should be consulted.

These guidelines provide introductory information in Sections 2 through 4, sections on health and safety considerations (Section 5), general landfarming applicability (Section 6) and the applicable standards (Section 7). The Guidelines themselves are provided in Section 8, where subsections take the user through the landfarming process starting from determining if landfarming is best suited to the particular contaminated site (Sections 8.1); followed by siting (Section 8.2); design and construction (Section 8.3); and operations, maintenance, monitoring and closure (Section 8.4). The landfarming process, from the contaminated site environmental assessment to landfarm closure, is depicted in a flowchart (see Figure 1-1).

2 INTRODUCTION

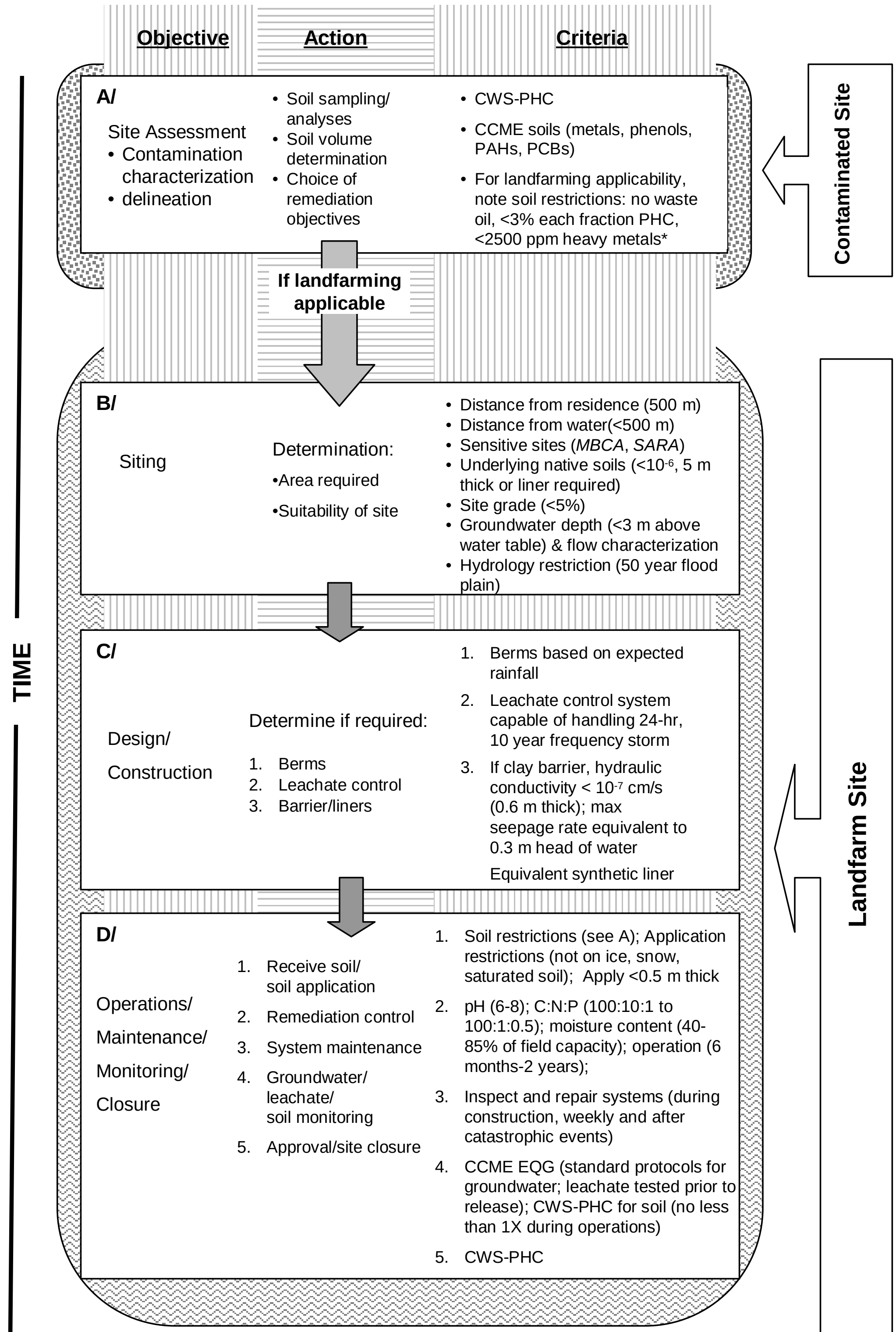
Landfarming is an *ex-situ* contaminated soil bioremediation technique that involves excavating and spreading contaminated material either in beds consisting of a thin, uniformly thick layer or in windrows. Remediation results from the manipulation of various conditions that stimulate aerobic microbial activity, such as:

- aeration (e.g., tilling);
- moisture content (e.g., irrigation or spraying);
- pH (e.g., buffering or neutralizing by adding lime);
- soil conditioning (e.g., addition of amendments such as bulking agents, nutrients, etc.)

Landfarming is also commonly known as land treatment, land spreading, or cell bioremediation. These latter two terms are more specific types of landfarming; land spreading is always passive (no aeration) and cell bioremediation involves specially-designed and lined treatment cells.

The mechanisms occurring during the landfarming process are various degrees of volatilization, dissolution into surface and ground water, sorption to the subsurface soils, and biodegradation. The relative contribution of each of these mechanisms to the treatment of the soil depends on the contaminant constituents, soil characteristics, and the landfarming control methods used. Responsible landfarming remediation manages these mechanisms such that biodegradation is the dominant mechanism; volatilization is minimized; contaminated surface waters are treated or re-circulated; and groundwater contamination is prevented through the use of liners.

Figure 2-1 outlines the steps required to properly select, design and manage a landfarm. The steps shown form the basis of the landfarming guidelines.



* Landfarming may still be applicable if soil blended prior to landfarming.
Note that entire process should be evaluated for determining applicability.

Figure 2-1 Process for Landfarming Guidelines for Federal Contaminated Sites

3 PURPOSE

Federal Guidelines for Landfarming Petroleum Hydrocarbon Contaminated Soils provide a systematic and thorough approach to landfarming in order to lend assurances that each federal contaminated site is addressed consistently throughout Canada, while taking into account regional differences and requirements. Providing a checklist of key parameters or recommendations on landfarm siting, design, construction, operation, monitoring and closure, these guidelines are meant to guide federal departments responsible for contaminated sites. Although the review and approval from jurisdictions other than federal sites has not been undertaken, these guidelines may prove useful for provincial/territorial and municipal governments; remediation contractors; and other stakeholders.

4 SCOPE

*Federal Guidelines for Landfarming Petroleum Hydrocarbon Contaminated Soils a*re applicable to federal sites contaminated with petroleum hydrocarbons. These guidelines apply to soils from federal contaminated sites and the landfarming of these soils on federal lands (including the case where landfarming operations are conducted at a separate property).

For sites in provinces/territories with existing landfarming guidelines, remediation of non-federal contaminated sites should adhere to those guidelines.

Federal Guidelines for Landfarming Petroleum Hydrocarbon Contaminated Soils take into account various federal acts and regulations including the *Fisheries Act*, the *Canadian Environmental Protection Act*, the *Canadian Environmental Assessment Act, the Migratory Bird Convention Act, and the Species at Risk Act.* When applying the landfarming guidelines, federal legislation as well as any applicable provincial/territorial regulatory requirements established for landfarming, such as permitting, record keeping, and monitoring, must be followed. No additional regulatory requirements are associated with these guidelines. These guidelines are not enforceable by legislation, but rather should be considered a tool for ensuring effective and consistent remediation throughout Canada.

5 HEALTH AND SAFETY CONSIDERATIONS

The consultant entrusted to conduct the environmental site assessment and/or construct and operate the landfarm facility shall be responsible for ensuring the health and safety of all its employees, sub-consultants, and others at the site in accordance with Part II of the Canada Labour Code (RS 1985, c. L-2) other federal and provincial legislation where applicable.

Consultants contracted to design, construct, operate and/or close a landfarm should develop a health and safety plan to be followed by all those on site. Requirements of the health and safety plan are provided in Appendix A.

6 GENERAL LANDFARMING APPLICABILITY

Landfarming has been proven effective in reducing the concentrations of various constituents of petroleum products ranging from those with a significant volatile fraction, such as gasoline (GOwen Environmental Limited, 2002; USEPA, 1994; Poland, *et al*. 2003), to semi-volatiles such as diesel (Chatham. 2003), to those that are primarily non-volatile, such as heating and lubricating oils (USEPA, 1994; Poland, *et al*. 2003). Very heavy oils or tar contamination are not suitable for landfarming (Poland, *et al*. 2003).

Among the most cost-effective and practical means of remediating contaminated soils, landfarming is particularly well-suited to remote regions. Landfarming is a simple remediation technique not requiring advanced skills to operate effectively. Although generally more land is required than other techniques, in remote regions of Canada there is often an abundance of suitable land.

The effectiveness of landfarming depends on contamination characteristics, soil characteristics and land availability. These parameters should first be determined so that the appropriateness of landfarming may be evaluated for a particular contaminated site. If such parameters are less than optimal, landfarming may still be effective provided there is some design or operational adjustments such as soil amendments to adjust for pH, for example. Applicability of this technique with less than optimal conditions, therefore, would depend upon these additional control measures, most of which would increase the construction, operational and maintenance costs.

Climatic conditions, such as extreme cold and precipitation, impacts landfarming operating times. Longer operating times are required for cold climates since biodegradation rates decrease as temperatures decrease. Although one would expect no biological activity to occur in frozen ground, researchers have shown petroleum hydrocarbon biodegradation at temperatures below 0^{o}C (Whyte and Greer, 1999; Whyte, *et al*. 2001 and 2003, Rike, *et al*. (2003)). Biological activity in low temperature regions can also be increased by the addition of nutrients such as nitrogen fertilizer (Rike, *et al.,* 2003). Regions with high precipitation rates may require time for soils to achieve a certain level of dryness in order to establish optimal oxygen levels for biodegradation.

7 APPLICABLE STANDARDS

The remediation of a federal, petroleum hydrocarbon contaminated site should follow the environmental site assessment steps as established by the following standards:

- Canadian Council of Ministers of the Environment (CCME) *Canada-Wide Standard for Petroleum Hydrocarbons in Soil* (CWS-PHC) (CCME, 2001);
- Canadian Standards Association (CSA) Environmental Site Assessment Standards Z768-01 (2001) and Z769-00 (2000), for Phase 1 and Phase 2; and,
- *Subsurface Assessment Handbook for Contaminated Sites* (CCME, 1994).

These documents are updated periodically; contact CCME and CSA for the most recent versions. Assuming that the site in question is known to contain primarily petroleum hydrocarbon contamination, following the procedure in the CWS-PHC is recommended. These landfarming guidelines are designed to harmonize with the CWS-PHC procedures. The CWS-PHC, in turn, allow for a risk-assessment approach. This could take the form of the CWS-PHC Tier 2 or 3 or, other tools to ensure equal or better protection, for example, the Risk-Based Corrective Action (RBCA) process. For information on the CWS-PHC and related documentation, consult with the on-line information available from CCME at http://www.ccme.ca/ourwork/standards.html.

Generic or site-specific remediation limits as per the CCME Environmental Quality Guidelines (EQGs) or CWS-PHC should be used to delineate the soil requiring treatment at the site and, once a landfarm is operating, to monitor the extent to which the soil has been remediated to acceptable levels. The parameters analyzed during the environmental site assessment should be evaluated using these guidelines to determined chemicals of concern (CoCs) and those identified should be tracked during the remediation process. For both the CCME EQGs and the CWS-PHC, the applicable land use criteria (e.g. Agricultural, Residential/Parkland, Commercial/Industrial) should be considered. The land-use of the site where the soils have been excavated as well as the site where the landfarmed soils will be ultimately placed must be determined.

As the CCME periodically updates these guidelines, the criteria are not reproduced here; consult the most recent CCME EQGs for criteria based on the contaminated site land use.

Groundwater and leachate criteria become applicable once the landfarm location is sited. As there is no federal standard available for groundwater, the approach as per the Environment Canada Contaminated Sites Management Working Group (CSMWG) policy: *A Federal Approach to Contaminated Sites* (CSMWG, 1999), is recommended. This policy recommends the use of appropriate provincial/territorial guidelines or criteria when there is an absence of similar guidelines/criteria available.

Groundwater sampling and analysis should adhere to the CCME sampling procedures (CCME. 1993). Leachate monitoring performed during the landfarm operations is primarily for characterization purposes only, as leachate is often recirculated over the landfarm as a means of irrigation (or stored in a tank in the event that irrigation may be required at some point in the landfarming season). If this tank is discharged into the environment, the CCME EQGs apply as a standard.

For any discharge which migrates from a federal site and on to a provincial property, conformance to pertinent provincial guidelines is required.

8 GUIDELINES

The following sections outline the main guidelines to be followed when choosing and applying landfarming procedures and techniques at a site. The guidelines are presented in the same order as the steps outlined in Figure 1-1, namely:

- Site assessment / landfarming suitability determination
- Siting
- Design and construction, and,
- Operation, maintenance, monitoring and closure.

8.1 Site Assessment / Landfarming Suitability Determination

8.1.1 Contaminant Type and Concentration Restrictions.

These landfarming guidelines are recommended for petroleum hydrocarbon contaminated soil remediation only. In order to reduce emissions from the volatilization of lighter, more volatile hydrocarbons, landfarming is recommended for treatment of mid-range petroleum hydrocarbon contaminated soils unless emission controls are employed. Very heavy oils or tar contamination are not suitable for landfarming (Poland, *et al*. 2003). Generally, these compounds contain polycyclic aromatic hydrocarbons (PAHs) which are difficult to biodegrade without enhancements. Contaminants that have been successfully treated include diesel fuel, No. 2 and No. 6 fuel oils, JP-5, and oily sludges (FRTR, 2002).

The characterization of the contaminants and contaminant levels in the soil determined during the environmental site assessment may be used to determine landfarming applicability. An evaluation of the type and degree of contamination helps to exclude soil material that might be toxic to certain species of microorganisms and also helps to determine if landfarming would be the appropriate remediation technology to be employed for the contaminants of concern. Although landfarming is recommended for petroleum hydrocarbon contaminated soils only, it is understood that other contaminants may also be present. Table 1 indicates the type of analyses recommended for contaminated soil characterization.

Table 1 Recommended Analyses Based on Suspected Soil Contamination[i]

Contaminant Source	Parameters Analyzed								
	CWS – PHC fractions	BTEX	TPH (calculated)	Lead	Total Heavy Metals[ii]	Chromium/ Cadmium	PCBs	Phenols	PAHs
unleaded gasoline	■	■	■		■				
leaded gasoline, aviation gasoline	■	■	■	■	■				
fuel oil, diesel, kerosene, jet fuel, mineral oil/spirits, motor oil	■	■	■		■				■
petroleum solvents	■		■				■		
crude oils, hydraulic fluids	■		■	■	■				■
waste petroleum products	■	■	■	■	■	■	■	■	■

[i] Modified from: Environment Canada, 1993.
[ii] Heavy metal analyses required to determine if constituents are not present at levels toxic to micro-organisms (>2500 ppm) (USEPA. 1994).

The following restrictions are recommended to avoid micro-organism toxicity:

- Total petroleum hydrocarbon (TPH) or total extractable hydrocarbons (TEH) < 3% (Yukon, 2004a and 2004b);
- total heavy metal concentrations < 2500 ppm (USEPA, 1994)[1];
- electrical conductivity (EC) < 4 dS/m; and
- sodium adsorption ratio (SAR) < 6 (Alberta EUB, 1996).

If any of the levels detected exceed these maximums, the contaminated soil should be considered hazardous waste and handled accordingly. Landfarming is not recommended for such contaminated soils.

As mentioned in Section 7, the CCME EQGs and CWS-PHC remediation limits should be used to delineate the soil requiring treatment at the site

8.1.2 Optimal Soil Characteristics

Prior to landfarm design, an evaluation of the soil characteristics provided in Table 2 will ensure that the contaminated soil is well-suited to landfarming.

8.1.3 Land availability

Often remote regions in Canada have plentiful suitable land available for a landfarm site. For less remote regions, land availability becomes a factor in technique applicability.
The area of land required may be easily determined by using the volume of excavated material and the expected landfarm soil depth of between 0.30 and 0.45 m. A maximum soil thickness of 0.5 m is recommended. A single plot or multiple plots may be required. Additional area surrounding the plot(s) for berms and leachate control should be considered.

8.1.4 Site Characterization

Prior to landfarm design, a characterization of the site where the landfarm is to be placed should be conducted to determine its suitability. Such a characterization includes a site survey; groundwater flow, direction and baseline chemical analysis; native soil hydraulic conductivity determination; and microbial identification determination and population. Such a characterization should include a review of adjacent properties that may be potentially impacted by the site, and determinations of distances from surface water bodies, buildings (and other permanent structures), and communities, if applicable. Specific requirements for siting the landfarm are outlined below in Section 8.2.

[1] Soils with heavy metal concentrations below this level but above remediation criteria, will have to undergo further treatment following landfarming to reduce heavy metal concentrations.

Table 2: Optimal Soil Characteristics for Landfarming

Landfarming Parameter	Optimal Characteristics
Microbial population density:	For landfarming to be effective, the minimum heterotrophic plate count should be 10^3 CFU/g (colony forming units/gram). Below this minimum, landfarming may still be effective provided the existing bacteria are stimulated using nutrients or the soil is amended to increase the bacteria population (USEPA. 1994) In the latter case, as noted in Section 8.4.2, adding non-indigenous bacteria to a site has had limited success in enhancing degradation of petroleum hydrocarbons. There are also regulatory restrictions associated with the addition of bacteria to sites (see Section 8.4.2).
Soil pH:	To support bacterial growth, soil pH should be between 6 and 8. Outside this range, landfarming may still be effective through soil amendments.
Moisture content:	Bacterial growth requires moisture, optimally between 40-85% of field capacity[2] (USEPA, 1994) Periodically, moisture may be added to landfarmed soil to maintain this moisture level. Excess moisture due to periods of high precipitation, during spring thaw or due to poor site drainage may need to be addressed. Site drainage may be improved through landfarm design, but uncontrollable influx of moisture may simply mean that longer operating times will be required for the landfarm.
Nutrient concentration:	For proper growth, micro-organisms require inorganic nutrients that may be naturally-occurring in the soil. Nitrogen and phosphorous may be added in the form of commercial fertilizer. For effective biodegradation, carbon:nitrogen:phosphorus ratios need to be between 100:10:1 and 100:1:0.5 (USEPA. 1994). This ratio may be calculated from the soil bulk density and the total hydrocarbon concentration.
Soil Type:	Clayey soils hamper biodegradation because of difficulties in aeration and the distribution of nutrients and moisture. Soil amendments such as gypsum and bulking agents such as sawdust, may be required. Clumpy soils may also require pre-treatment in the form of shredding, in order for landfarming to be effective. Very coarse soils are not suitable to landfarming as they do not retain moisture and nutrients (University of Saskatchewan, 2002). Volatile compounds will also volatilize more readily from course-grain soils than from fine grain soils. Typically, large diameter soil particles have a low contamination concentration due to their low surface area. As such, these particles can be screened out prior to placing soils in the landfarm.

[2] The most reliable measure of moisture content is expressed as a percent of field capacity (also referred to as "soil capacity"). Field capacity itself is the maximum %-weight of moisture the unconfined, gravity-drained soil can retain. An example would be a sandy soil with a field capacity of 25%, meaning a maximum of 250 grams of water retained in 1,000 grams (dry wt.) of unconfined soil. Typically the target moisture content is expressed as a percent of the field capacity; for example, 50% of field capacity for the above sandy soil would be 125 grams water per 1,000 grams dry soil.

8.2 Siting

8.2.1 Distance from Residential Zoning

A landfarm should be sited greater than 500 m from a residential boundary.

8.2.2 Distance from Surface Water Body

A landfarm should be sited greater than 500 m from a permanent surface water body. This restriction applies to both potable and non-potable surface waters.

8.2.3 Distance from Potable Groundwater Wells

A landfarm should be sited greater than 500 m from a potable groundwater well.

8.2.4 Sensitive Areas Restrictions

When siting a landfarm the provisions presented in the *Migratory Birds Convention Act (MBCA)* and the *Species at Risk Act (SARA)* should be followed. Although landfarms are not mentioned, the provisions within the Acts relate to the protection of habitat for various species of flora and fauna. In addition, permits are required under the *Species at Risk Act* for any work conducted where a sensitive species may exist.

There should also be sensitivity towards the protection areas important to aboriginal peoples. Potentially affected First Nations, Métis or Inuit representatives should be consulted prior to siting a landfarm.

8.2.5 Underlying Geology/Native Soils

The geology of the site needs to be considered (e.g. thickness of underlying soil, the presence of bedrock, degree of fracturing) to determine the need for a liner/barrier (see Section 8.3.9). It is recommended that at landfarm sites with less than 5 m of low hydraulic conductivity ($<10^{-6}$ cm/s) native underlying soil, a liner/barrier be used.

8.2.6 Site Grade

The landfarm should be sited at a location with a natural slope of less than 5 %; otherwise the site will require grading.

8.2.7 Hydrology

The landfarm should be sited where the groundwater table is greater than 3 m from the surface. When there is a need to excavate during landfarm construction, cultivation no closer than 3 m above the groundwater table must be ensured. Using groundwater flow direction and rate data, the landfarm should be sited such that groundwater contamination is avoided (otherwise, a barrier to groundwater flow is necessary).

A landfarm should not be sited on land within a 50 year floodplain.

8.3 System Design/Construction

8.3.1 Evaluation of Landfarm Design/Operational Requirements

The previous sections on landfarm applicability need to be evaluated to determine whether landfarming is the most suitable treatment for a particular contaminated site. Further landfarming considerations related to design and operations, listed below, should be considered prior to choosing landfarming as a remediation technique for a particular contaminated site.

- Scale of operations
- Equipment availability
- Design by qualified persons requirement
- Emission control system requirement
- Site security requirement
- Run on/run off control system requirement (berms)
- Leachate control system requirement
- Liner/barrier requirement
- Placement of soil in landfarm
- Closure procedures

These considerations may increase the cost of remediation depending on the level of sophistication required. Once the landfarm site has been determined, then the design and operational considerations may be fully realized. Details of these requirements are provided in the following sections.

8.3.2 Scale of Operations

The scale of operations should be considered prior to designing the landfarm. Operations may range from the one-time spreading of soil in a temporary facility to multiple applications from multiple sources in a permanent facility.

8.3.3 Equipment Availability

Often remote communities have very limited land-moving equipment, or the equipment is unavailable for the desired remediation construction or operation times. Downtime for equipment breakdown and repair should be anticipated and factored into the construction/operations plan.

8.3.4 Qualifications for Design Contractors

The following qualifications are recommended for consultants hired to design the landfarming remediation project (modified from MOE, 2004):

a) Professional Designations:

   - Professional Engineer (required to approve and seal design drawings.)
   - Professional Geoscientist
   - Chartered Chemist
   - Professional Agrologist

b) Education requirement: Minimum 4-year degree in:

- Science
- Engineering or
- Applied Technology

c) Experience requirement:

- with a doctoral degree, 5 years of experience;
- with a master's degree, 7 years of experience;
- otherwise, 8 years of experience.

Within the 5, 7 or 8 year periods of required experience, at least 2 years of experience are required in the field of soil remediation.

d) Professional liability insurance requirement: $1M for all types of qualified persons.

8.3.5 Emission Control

Emissions from landfarms can be a concern, particularly if highly volatile contaminants are being treated. If highly volatile contamination requires remediation, an emission control system should be implemented for the operations in order to reduce contamination from volatilization. As this option increases the sophistication of this remediation technique, it is not often included in the landfarm design. A certain degree of volatilization occurs during the excavation and soil application processes; every effort should be made to minimize soil disturbance during handling.

8.3.6 Site Security

At minimum, staking and identification is required at the landfarm site. If public or wildlife access is expected to be a concern, fencing is required. Signage denoting the responsible authority, operating period, and type of hazard (e.g. petroleum contaminated soil) is recommended.

8.3.7 Berms

For controlling run-on and run-off from the landfarm, a containment system should be used. To collect run-off, natural or engineered berms or ditches may be constructed around the entire perimeter of the treatment area, or in a select area, as required.

8.3.8 Leachate Control

A means to collect and treat run-off from the landfarm may be necessary. A leachate control system capable of handling a 24 hour duration, 1:10 year frequency storm is required in such a case. Leachate may be recirculated over the landfarm soil surface as a means of irrigation to maintain optimal biodegradation rates, or discharged if surface water analyses indicate contaminant levels are within CCME EQGs.

8.3.9 Barriers/Liners

When native soils at the landfarm site have high conductivity (see Section 8.2.5), a barrier or liner having a maximum seepage rate equivalent to clay liner under 0.3 m head of water or a

10^{-7} cm/s hydraulic conductivity at a thickness of 0.6 m, should be used beneath the soil to be treated.

8.3.10 Placement of Soil in Landfarm

A contaminated soil depth less than 0.5 m within cell(s) or in windrows is recommended. However, the type of equipment available for tilling, as well as the land availability, will dictate soil depth. Typically, landfarming is practiced with soil depths between 0.30 and 0.45 m. Contaminated soil should not be applied on a continuous layer of snow or ice or when the existing soil base is saturated with moisture.

8.3.11 Closure Procedures

During the system design phase, it is important to determine the requirements for site closure once remediation is complete. By laying out the closure procedures at this time, the responsible party or site sponsor can reviewed and endorsed them prior to proceeding with the system construction. This closure plan must be consistent with the current land use and will need to recognize how future land use changes or ownership will be taken into consideration after landfarm closure.

8.4 Operations and Maintenance

8.4.1 Operation Period

The operating period of a landfarm depends mainly on climatic conditions found at a particular landfarm site. Although a few petroleum hydrocarbon-degradable micro-organisms have been found to be active at temperatures below 0^{o}C (Whyte and Greer, 1999; Whyte, *et al*. 2001 and 2003; Rike, *et al*. 2003), most biodegradation occurs above freezing. Research has shown appreciable biodegradation may occur after one summer season, additional biodegradation over a second season is usually required. Therefore, it is recommended that the landfarm should operate for between 6 months to 2 years. This operation period assumes optimal conditions are maintained (i.e. regular tilling; moisture control; nutrient amendment, if required). Soil sampling and analyses are required to confirm remediation progress and completion.

8.4.2 Microbial Population Density Monitoring

As stated in Section 8.1.2, landfarming effectiveness is ensured with a minimum heterotrophic plate count of 10^3 CFU/g. Monitoring of the microbial population should be conducted during the landfarm operations if remediation progress is suspected to be stalled (e.g. after a freeze or drought).

Although amending soils with bacteria has had limited success (SAIC. 2004), some commercially-available inoculates may be used, particularly in southern regions of Canada. Cold-adapted microorganisms native to arctic and sub-arctic regions are not readily available. If microbial amendments are being considered, the user should be aware that products containing microorganisms, biochemicals (such as enzymes) or biopolymers, are "biotechnology products" and may be subject to the New Substances Notification (NSN)

Regulations, pursuant to the Canadian Environmental Protection Act, 1999 (CEPA, 1999). (Contact the New Substances Division of Environment Canada and http://www.ec.gc.ca/substances/nsb/eng/index_e.htm for more information.)

8.4.3 pH Maintenance

The optimal pH for landfarming operations is between 6 and 8. The soil pH may be increased with the addition of lime and decreased with the addition of elemental sulphur.

8.4.4 Moisture Content Monitoring

The amount of moisture in the landfarm soil impacts biodegradation and, therefore, should be monitored and adjusted if possible and necessary. If moisture levels are too high, the movement of air through the soil is restricted thereby reducing oxygen availability. Effective moisture levels are 40 - 85 % of water-holding capacity in the soil, but 20 – 85 % will support microbes. Water spraying is often needed during summer months, particularly prior to tilling, in order to reduce wind erosion. Soil may be amended with organic matter to increase moisture retention. A rule of thumb is the soil should be moist, not dry and dusty or dripping wet.

8.4.5 Nutrient Amendments Requirements

Biodegradation requires that micro-organisms are meeting nutritional requirements. The optimal range of carbon:nitrogen:phosporus (C:N:P) is 100:10:1 to 100:1:0.5. If the available nutrients are not sufficient, soil amendment in the form of commercial fertilizers, is required. Note that the addition of nitrogen may inadvertently lower the pH. Nutrients can be supplied to the soil in either liquid or solid form. Solid nutrients can be added directly to the soil when the soil is mixed prior to placement in the landfarm or during tilling events once the landfarm is operational. Liquid nutrient can be added to watering or irrigation systems. The frequency of nutrient addition can be reduced by using slow release nutrients.

8.4.6 Tilling

Tilling, with a rototiller or turning over the soil with a backhoe or other similar equipment, is a means of aerating the soil. This provides oxygen for the micro-organisms as well as distributes nutrients and moisture in the soil, thereby aiding biodegradation. Tilling is recommended once per month during the operating season of the landfarm, provided the soil is uniformly moist but not saturated. Tilling when soil is excessively wet is unproductive, whereas tilling while the soil is excessively dry may erode the soil and cause wind-blown dust problems.

Tilling must be carefully carried-out by an experienced operator, since it is possible to disturb or damage the liner placed under the contaminated soil.

8.4.7 System Maintenance

Maintenance of the landfarm is essential in ensuring its effectiveness. At some appropriate point during landfarm construction, inspection of the synthetic liner(s) should be conducted to ensure that the seams and joints are tight, and that there is the absence of punctures, blisters or tears. Imperfections (e.g. lenses, cracks, channels) can occur in soil and clay liners. Weekly, during landfarm operations, and immediately after a major storm or catastrophic event, inspections should be conducted on the:

(i) drainage control systems for evidence of deterioration, malfunction, leaks or improper operation, and

(ii) leachate collection systems to ensure proper functioning and to determine if leachate is being generated or is accumulating.

If any defects or malfunctioning works are detected, immediate repair is required to maintain the integrity of all works.

The drainage control system should be inspected as necessary/required during periods of precipitation or spring thaw to ensure control measures are taken if the system is approaching its capacity.

8.4.8 Monitoring and Closure

When monitoring the soils on the landfarm, samples should be taken at regular intervals from various parts of the landfarm, dependent upon the scale of the landfarm operations. A sampling plan should include sampling methods (grid, composite) and frequency (number of samples per surface area). Since the landfarmed material is relatively thinly applied and homogenized through tilling, only one depth of sample collection is required. The samples should then be analyzed for the contaminants of interest and compared with the remediation guidelines presented in the CCME EQG and the CWS-PHC documentation. These protocols are recommended for the landfarm soils to determine at which point the soils have been remediated and the landfarm can be closed. Monitoring of contaminant levels in the leachate is only required prior to discharge to the environment; during recirculation, testing may be done for purposes of tracking remediation progress. It is also recommended that groundwater on-site be monitored and compared to the appropriate CCME EQGs. Table 3 summarizes the criteria that should be used for the various media involved in landfarming operations.

The landfarm soils may be considered remediated once analyses confirms these soils are within the CCME EQGs or CWS-PHC for the particular land use of the property. The remediated soil may then be used in a manner that is consistent and appropriate with the site use. If other contaminant levels (such as heavy metals, PCBs, etc.) exceed CCME EQGs, the landfarmed materials should be then further remediated using an alternative remediation technique.

Table 3: Summary of Landfarming Standards for Federal Contaminated Sites

Media Monitored	Criteria
Landfarm soil and soil remaining at the delineated (excavation) site	Canada Wide Standard for Petroleum Hydrocarbons (CWS-PHC) (CCME, 2003)
	Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health (CCME, 2003)
Groundwater	Non-potable - none; as per *A Federal Approach to Contaminated Sites* (CSMWG, 1999) whereby provincial/territorial guidelines are recommended. Potable - Guidelines for Canadian Drinking Water Quality (Health Canada, 1996)
Leachate	For recirculation – none (operations monitoring only) For discharge to environment ▪ Into surface water: CCME Environmental Quality Standard (EQS) for Freshwater Aquatic Life (CCME, 2003) for surface water reception; and ▪ Into groundwater: none, as per *A Federal Approach to Contaminated Sites* (CSMWG, 1999) whereby provincial/territorial guidelines are recommended
Surface Water	CCME Environmental Quality Standard (EQS) for Freshwater Aquatic Life (CCME, 2003) or, for potable water, the Guidelines for Canadian Drinking Water Quality (Health Canada, 1996)
Ambient Air	Canadian National Ambient Air Quality Objectives: Process and Status (CCME, 2003)

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APPENDIX A – Health and Safety Plan (HASP) Requirements for Landfarming at Federal Contaminated Sites

A.1 Purpose and Scope

- The Consultant shall be responsible for ensuring the health and safety of all its employees, sub-consultants, and others at the site in accordance with the Part II of the Canada Labour Code (RS 1985, c. L-2) and applicable provincial legislation as required.

- Since landfarming is an *ex-situ* technique, it may require excavation and transport of contaminated soil off-site or to another location within the contaminated site property. As such, the environmental site assessment (ESA) for the original site is not within the scope.

A.2 Plan Applicability

The HASP is applicable to the landfarming

- Consultant and any sub-consultants;

- Workers, supervisors and visitors to the contaminated site and landfarm site and those workers transporting contaminated materials between sites;

All those on-site must be briefed on the site hazards and must read and sign the Health and Safety Plan.

A.3 Background

A.3.1 Site Name and Location

A.3.2 Site History

A.3.3 Site Activities (e.g. site excavation; materials handling; landfarm site characterization; hydrological investigations; landfarm construction, operations, monitoring, etc.)

A.4 Chemical Hazards

- Soil contaminants (exceeding specified standards) listed

A.4.1 Personal Protective Equipment (PPE)

All workers are required to:

a) Wear dedicated work clothes, preferably coveralls, and safety boots;
b) Wash work clothes and boots prior to storing at home or at the workplace;

c) Wear disposable nitrile, or other material as approved by the Safety Officer, gloves while handling contaminated soils or potentially contaminated tools;
d) Shower at the end of each work day when dealing with contaminated soils;
e) Wash hands and face prior to eating, smoking or chewing gum;
f) Have immediate access to first aid care and equipment, including an eye-wash station.

All workers in the active excavation zone are potentially exposed to petroleum hydrocarbon vapour through soil handling activities must meet the above requirements, and:

a) Work in a manner that reduces the potential exposure to dust, such as periodically wetting the work.
b) Wear a disposable HEPA face mask with organic filter cartridges;
c) Have access to goggles should, at the discretion of the Safety Officer, dust levels become high enough that there is a significant risk of eye exposure;
d) Wash work boots at the end of each work day or wear disposable boot covers and discard at the end of each work day.

The above PPE has been prescribed based on consultations with Health Canada, Occupational Health and Safety Agency (Nordin, *pers. com*. in Aldridge, *pers. com*.) Depending on actual site conditions, the Safety Officer, or designated alternative, may upgrade or downgrade the PPE requirements.

A.4.2 Air Monitoring & Action Levels

- Air monitoring prior to and during the excavation;
- To evaluate the background and exposure concentrations in the workplace to determine if personal protection is warranted.

A.5 Physical Hazards

- Assessment and mitigation of various physical hazards (e.g. potential tripping hazards, overhead hazards while working under the deck structure, puncture and laceration hazards from excavation equipment, heat stress).

A.6 Site Safety Inspections

- Periodic routine safety inspections to identify any hazards that may not have been anticipated by this plan and to insure that the health and safety of workers is adequately protected.

A.7 HASP Modifications

- The HASP may be modified according to site conditions.

A.8 Emergency Contacts

A.9 Sign-Off

- Designated health and safety representatives are required to have read and approved the Health and Safety Plan, and provide a signed record as such.